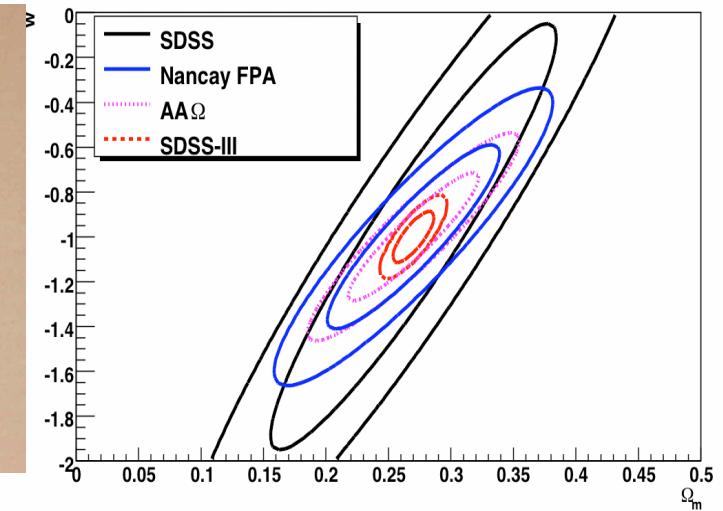
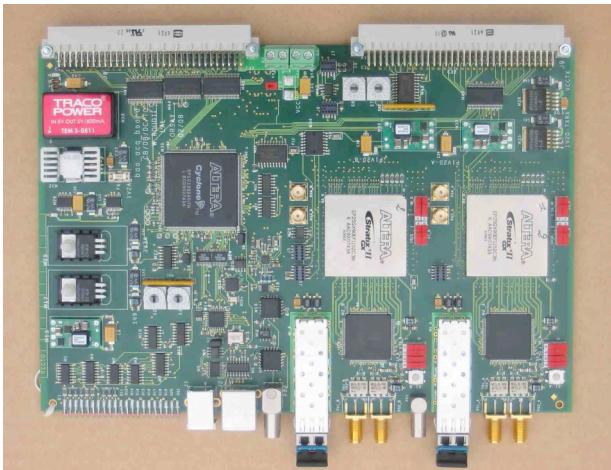


BAO studies with the FAN project



**FAN project: GEPI, USN, LESIA, LERMA
IN2P3/LAL, CEA-Saclay (Irfu)**

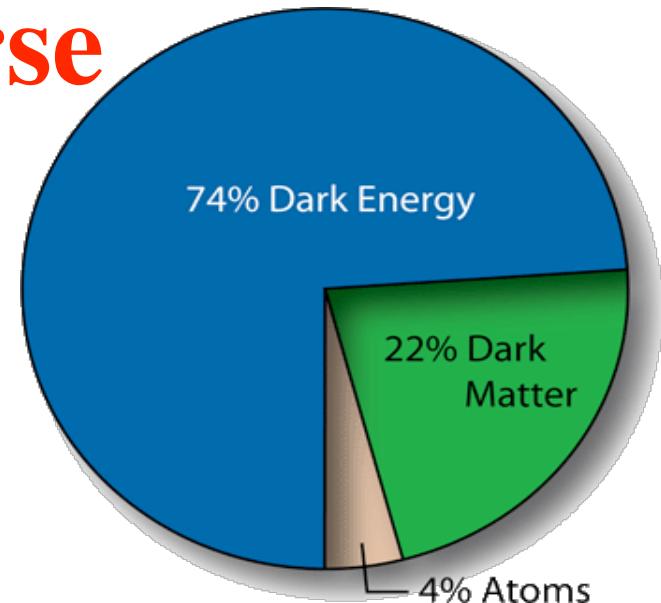
Fermilab, oct. 8th 2009

Marc Moniez (LAL IN2P3)

*Dark energy
Acoustic Baryonic
Oscillations*

The content of the Universe

- ⇒ Current observations in favor of a flat Universe
- ⇒ Energy density seems now dominated by a component that behaves like cosmological constant Λ
- ⇒ Λ acts against gravity
- ⇒ Vacuum energy (quantum fluctuations) \rightarrow dark energy ?
- ⇒ State equation for this new fluid :
 $p = w(z) \rho$
- ⇒ $w(z) = -1$ for cosmological constant Λ

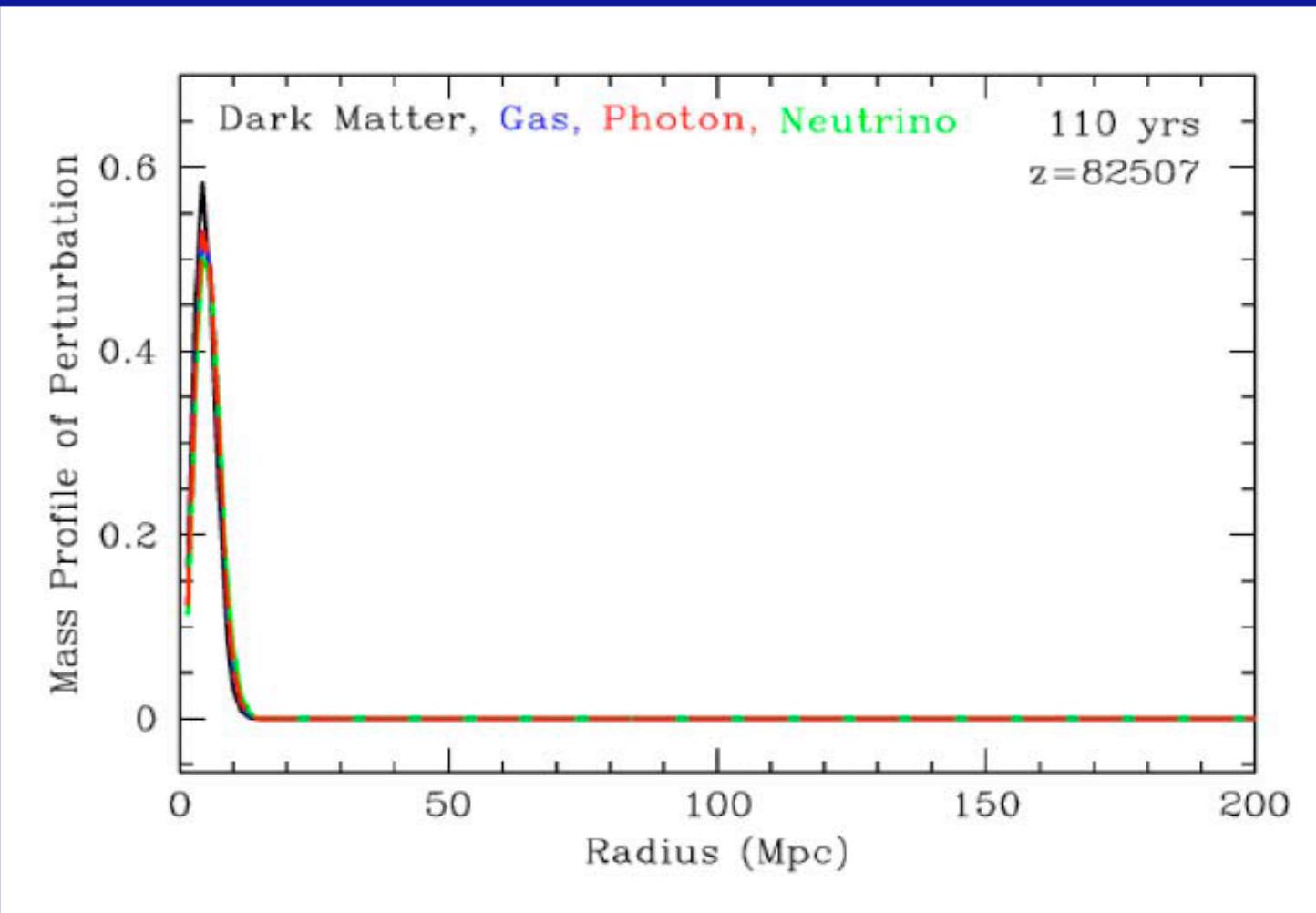


Parameter	Symbol	Value
Hubble parameter	h	0.73 ± 0.03
Total matter density	Ω_m	$\Omega_m h^2 = 0.128 \pm 0.008$
Baryon density	Ω_b	$\Omega_b h^2 = 0.0223 \pm 0.0007$
Cosmological constant	Ω_Λ	See Ref. 2
Radiation density	Ω_r	$\Omega_r h^2 = 2.47 \times 10^{-5}$
Neutrino density	Ω_ν	See Sec. 21.1.2
Density perturbation amplitude	σ_8	0.76 ± 0.05
Density perturbation spectral index	n	$n = 0.958 \pm 0.016$
Tensor to scalar ratio	r	$r < 0.65$ (95% conf)
Ionization optical depth	τ	$\tau = 0.089 \pm 0.030$
Bias parameter	b	See Sec. 21.3.4

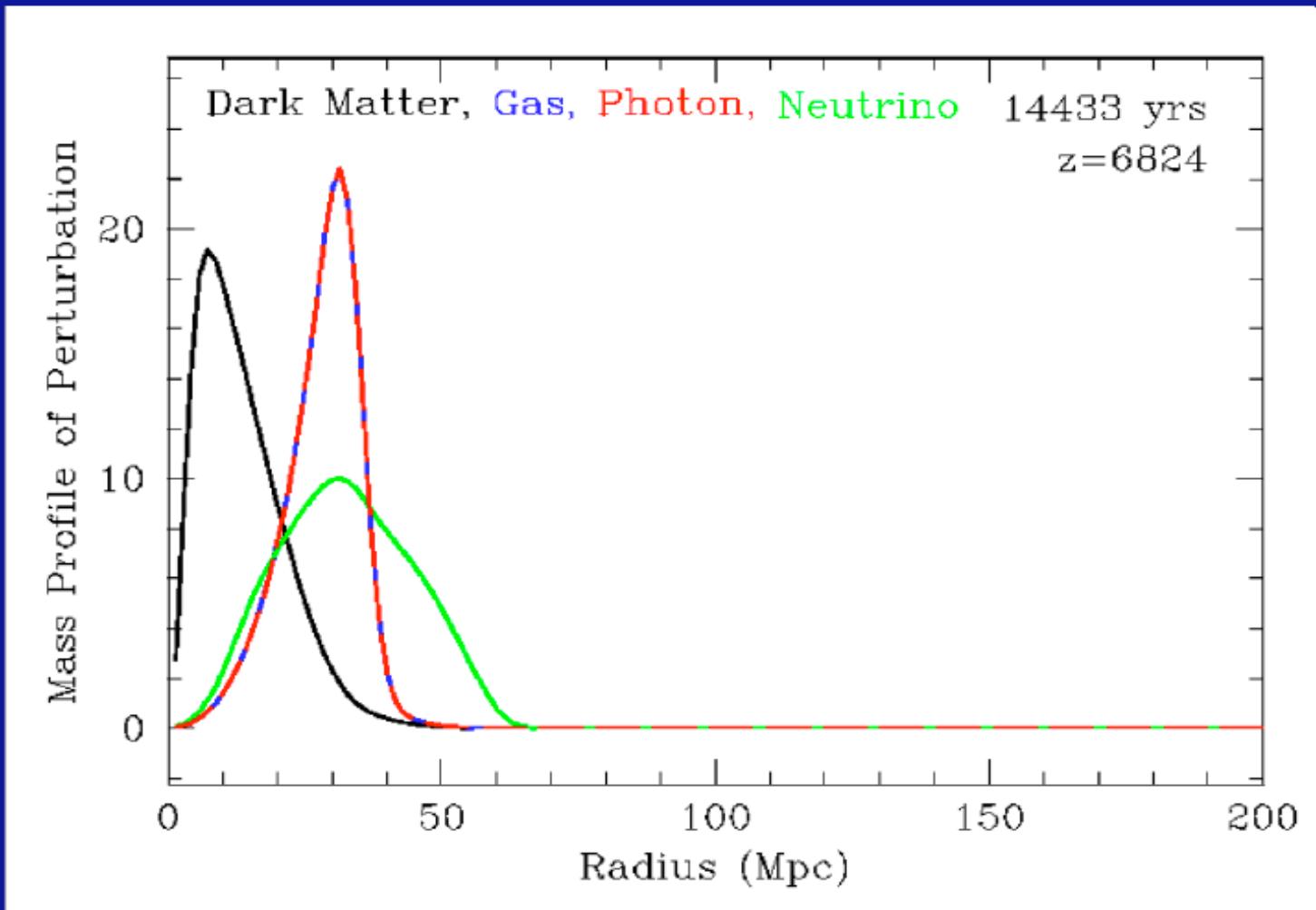
Cosmological probes

- ⇒ **Baryonic Acoustic Oscillations (BAO)** : measure a characteristic scale in the galaxy spatial distribution → $d_A(z)$, $H(z)$
- ⇒ **Supernovae** : measure the apparent luminosity of the SNIa as a function of z → $d_L(z)$
- ⇒ **Gravitational weak lensing** : measure local distortions of the galaxy orientation distribution → $d_A(z)$, structure formation
- ⇒ **Galaxy clusters** : cluster counting and spatial distribution → $d_A(z)$, $H(z)$, structure formation
- ⇒ **Integrated Sachs-Wolf effect**: descent and ascent of photons in a potential well that varies over time

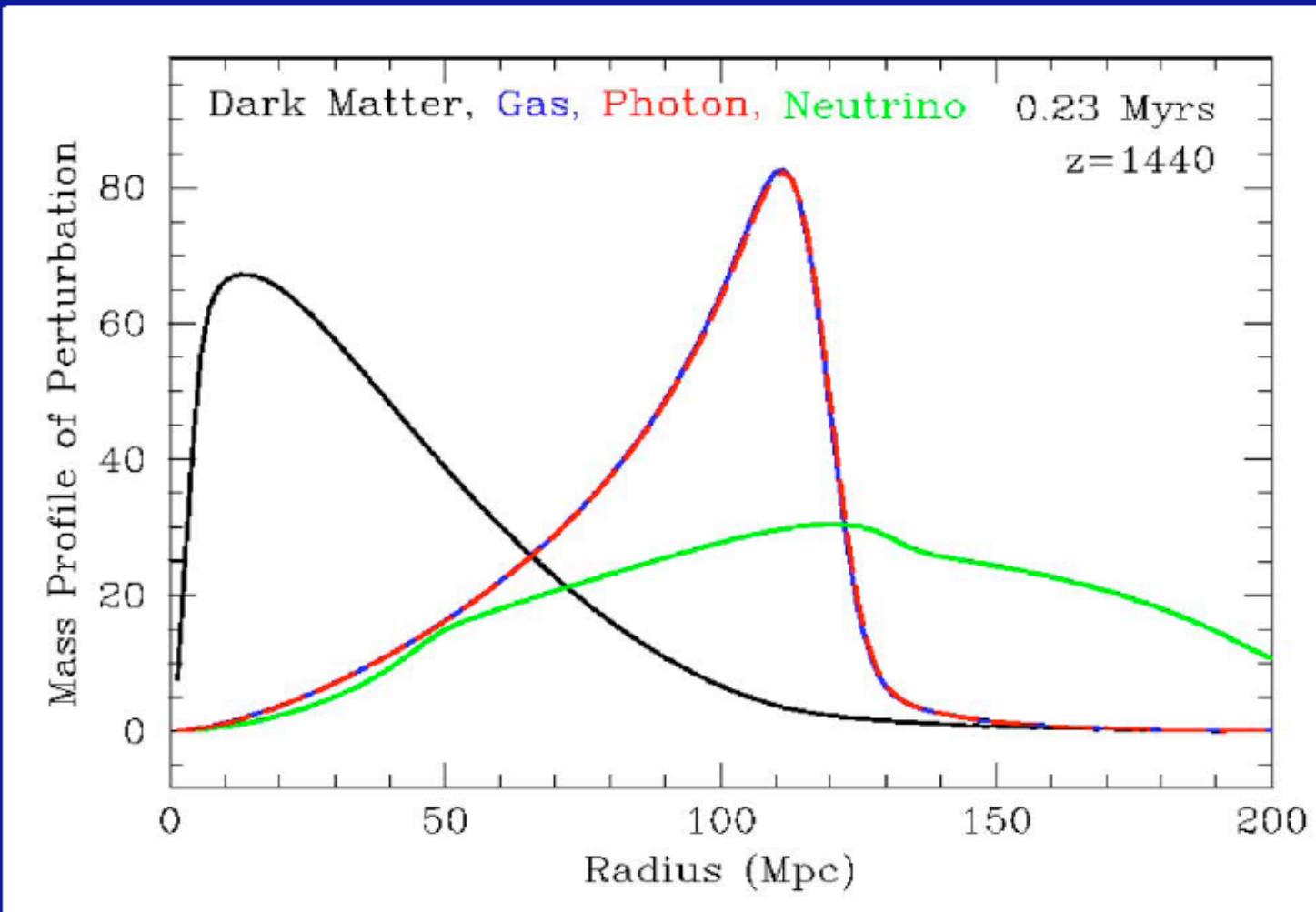
Baryonic Acoustic Oscillations



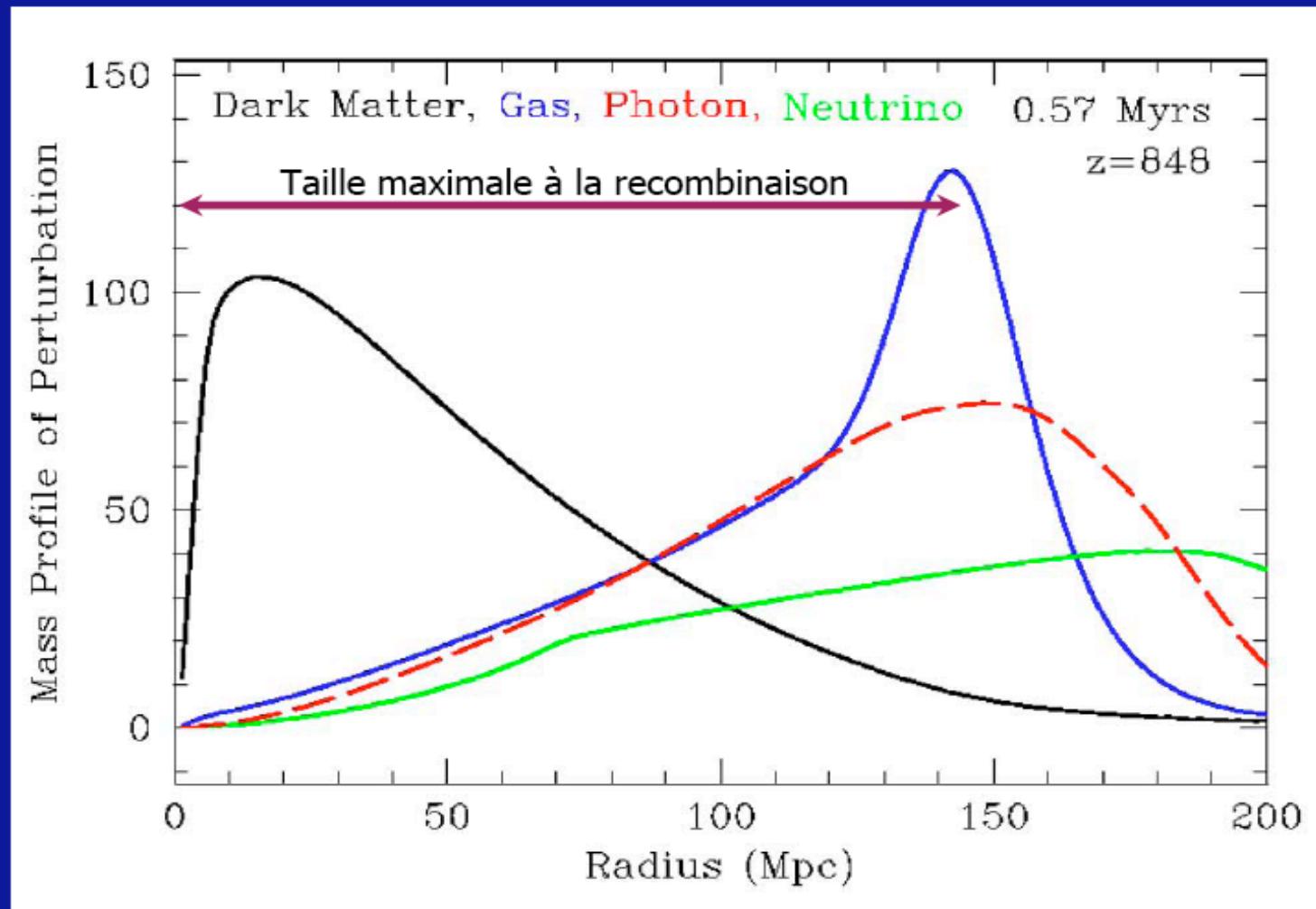
Baryonic Acoustic Oscillations

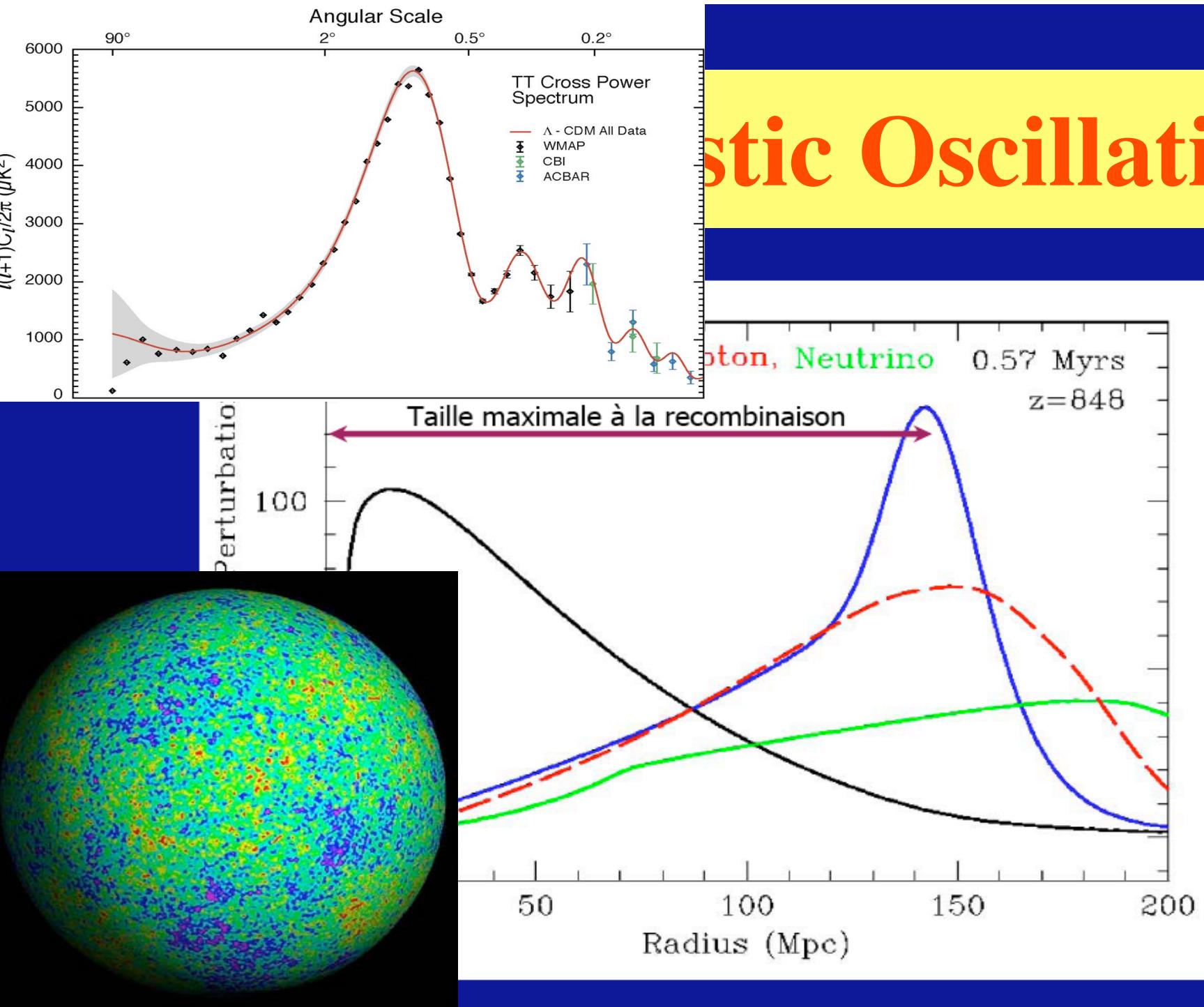


Baryonic Acoustic Oscillations



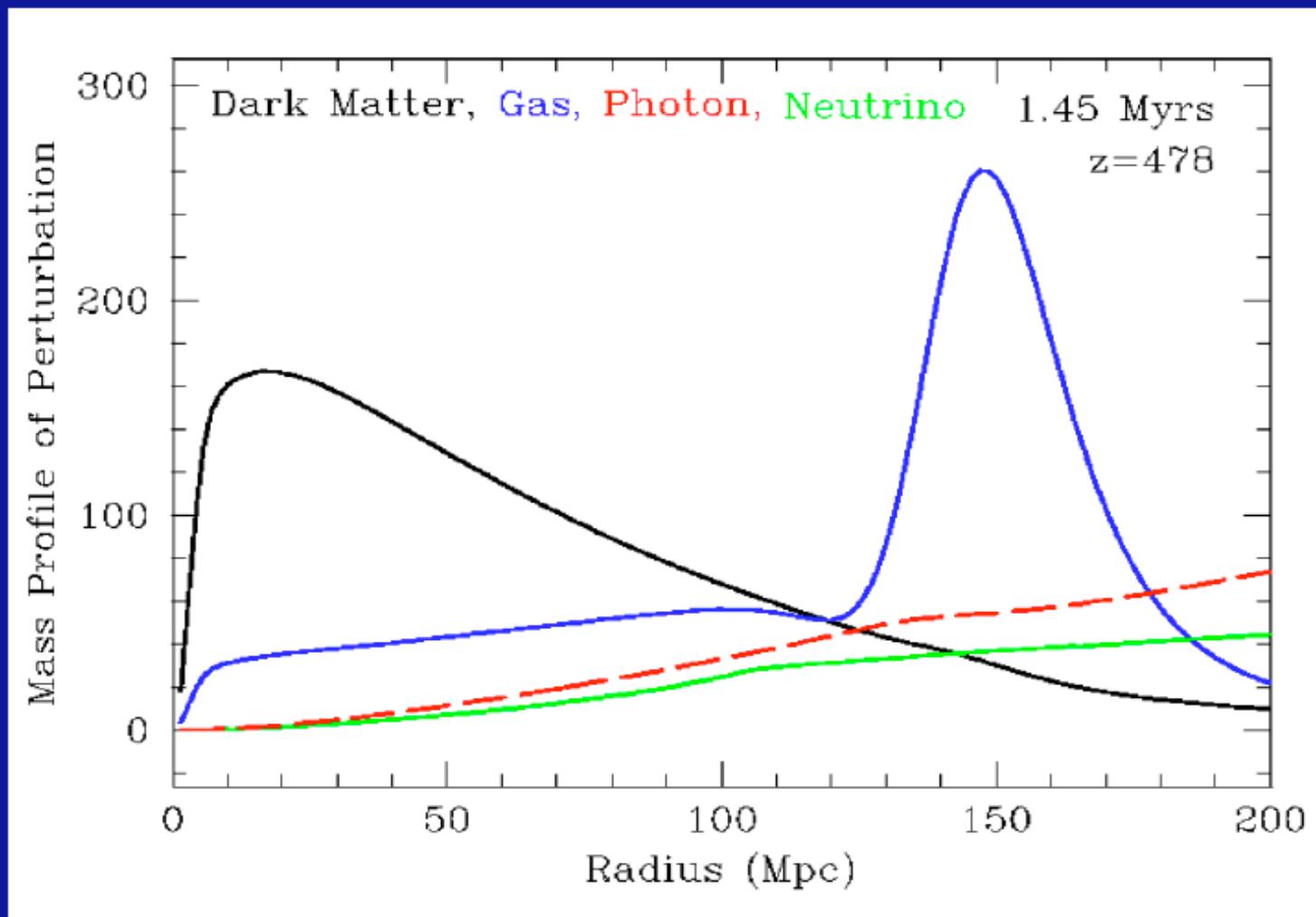
Baryonic Acoustic Oscillations



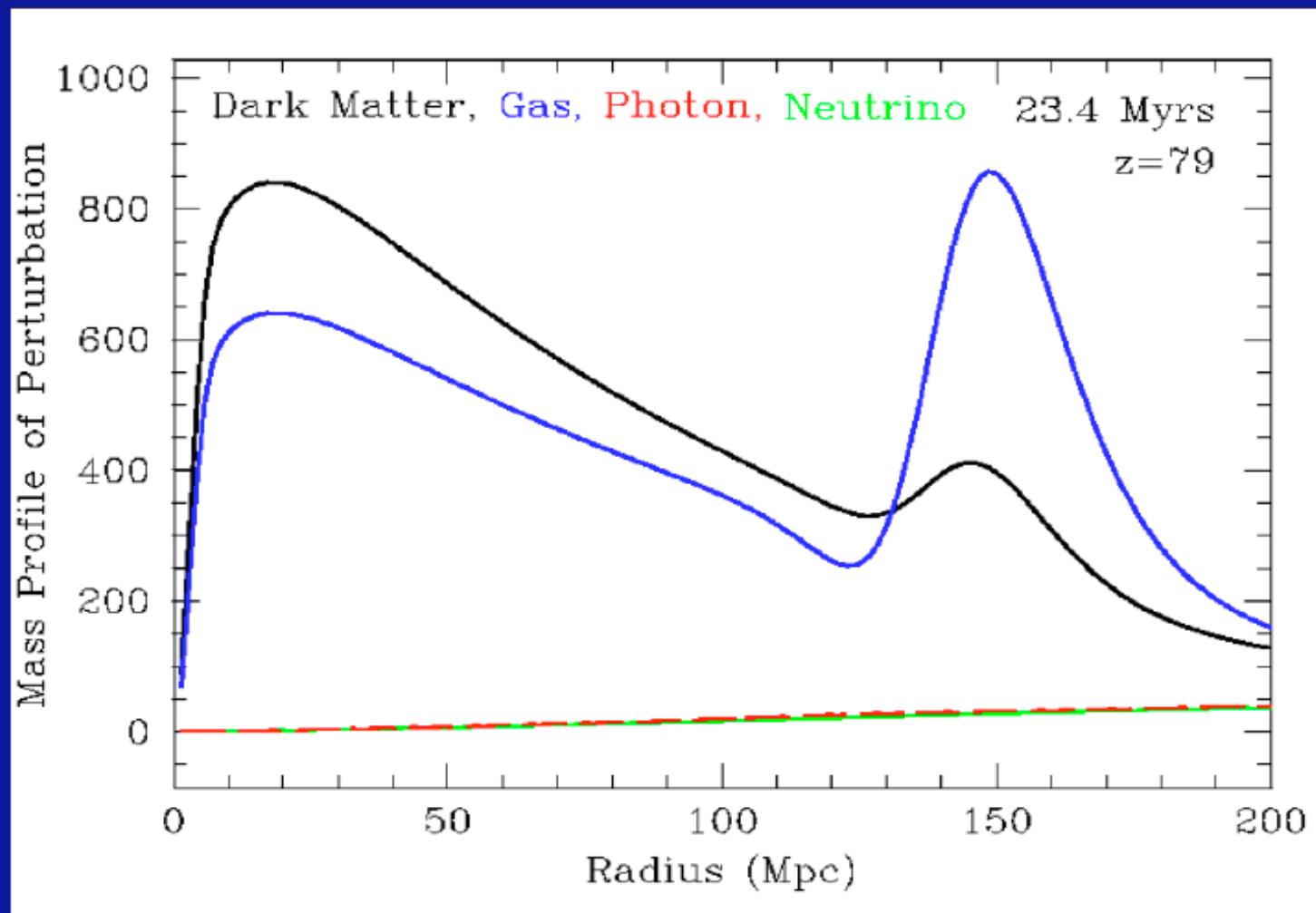


Stochastic Oscillations

Baryonic Acoustic Oscillations



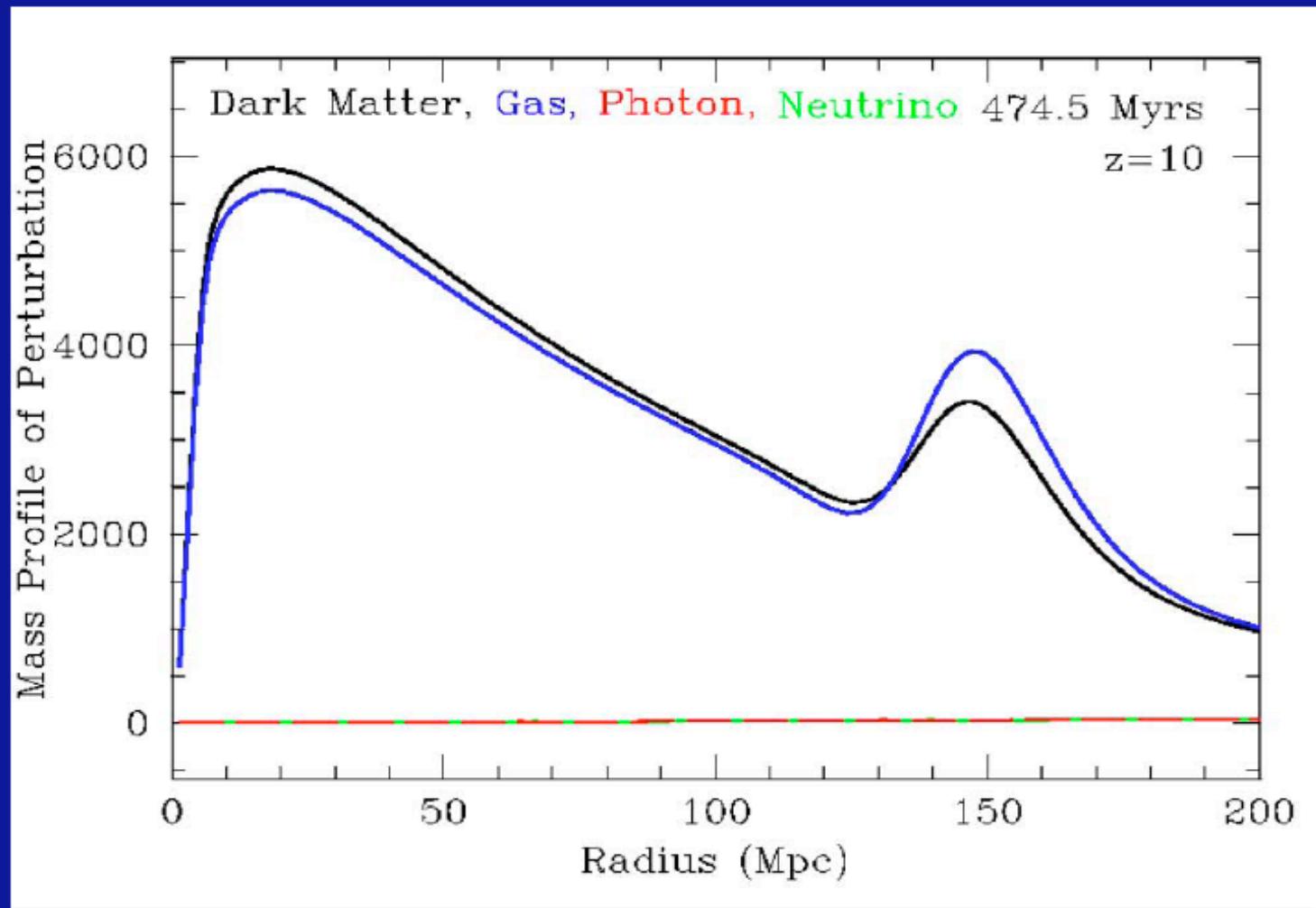
Baryonic Acoustic Oscillations



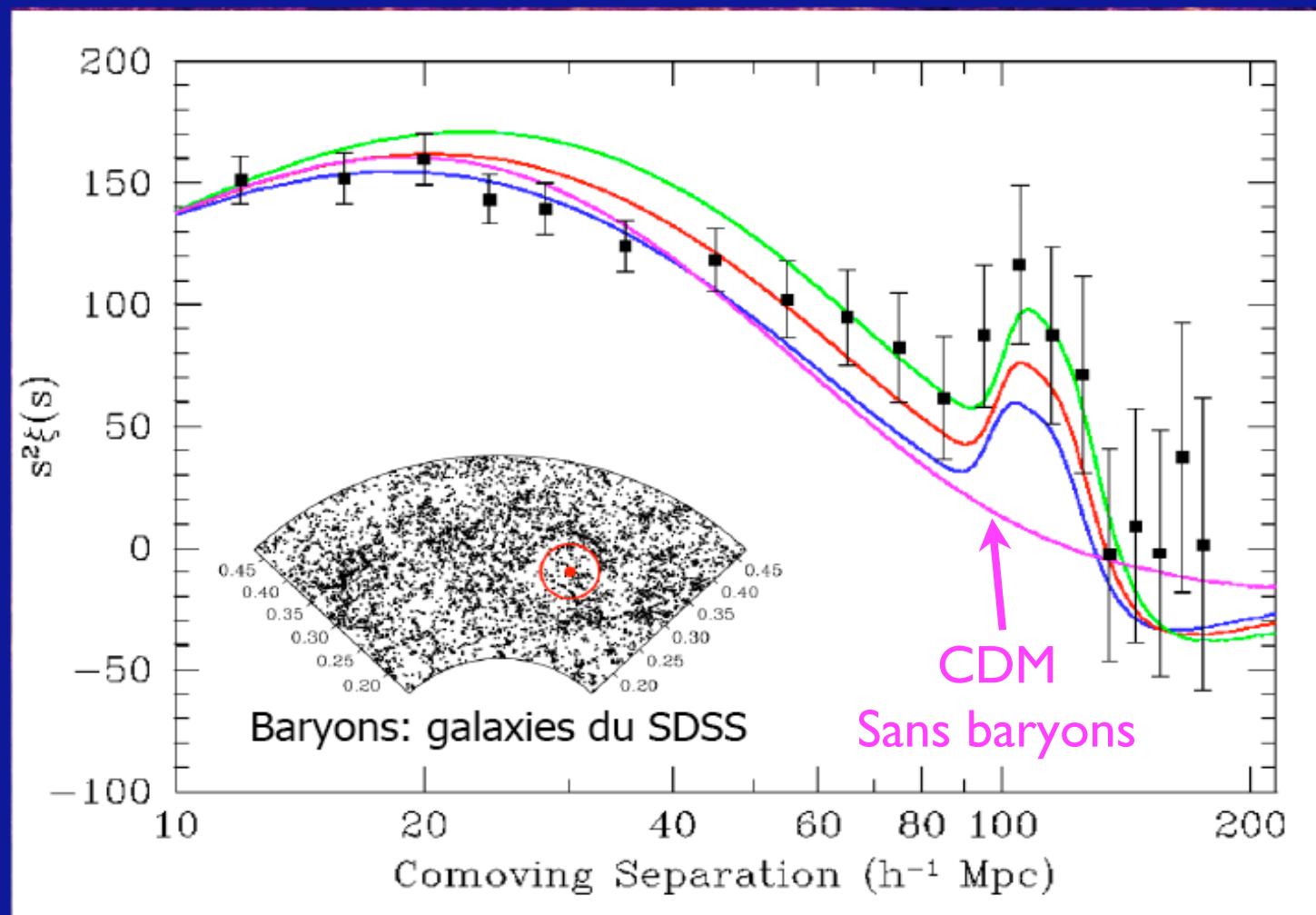
Baryonic Acoustic Oscillations

- ⇒ Inprints of the oscillations of the baryon-photon fluid in the ordinary matter distribution after structure formation
- ⇒ The baryonic matter distribution follows the dark matter modulation, in structures resulting from density fluctuation growing

Baryonic Acoustic Oscillations

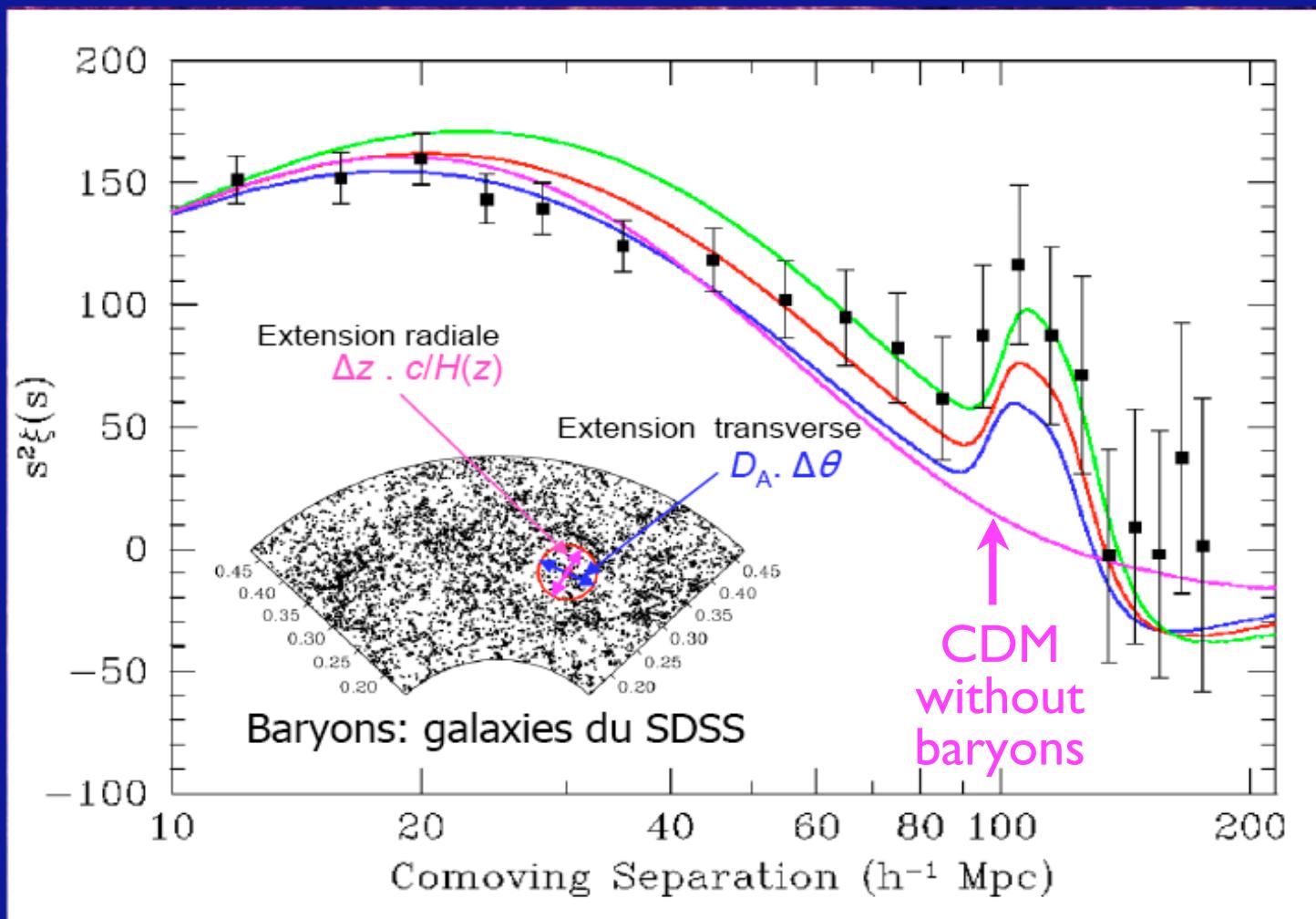


Baryonic Acoustic Oscillations



Baryonic Acoustic Oscillations

SDSS - D. Eisenstein et al.



Baryonic Acoustic Oscillations

- ⇒ Inprints of the oscillations of the baryon-photon fluid in the ordinary matter distribution after structure formation
- ⇒ The baryonic matter distribution follows the dark matter modulation, in structures resulting from density fluctuation growing
- ⇒ Cosmological probe of standard ruler type (D_A)
 - With a measurement @ $z \sim 1100$ as a bonus (CMB anisotropies)
- ⇒ Use tracers of baryonic mater:
galaxies (LSST) or H_I (radio@21cm) with distinct biases

Baryonic Acoustic Oscillation with radio-detection

Microwave (CMB)

measures the BAO scale at $z = 1100$

Optical survey (SDSS)

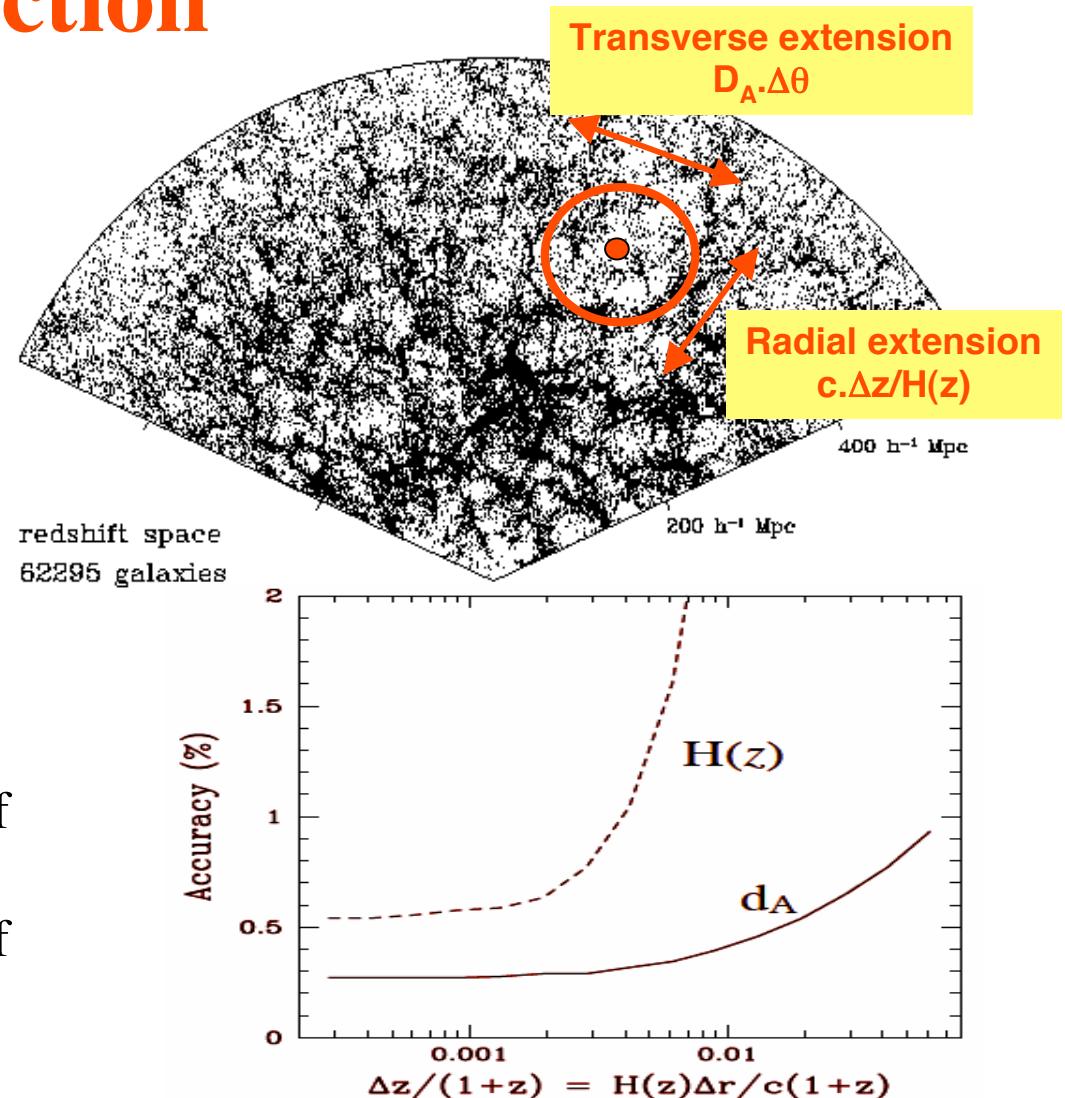
measures the BAO scale at $\langle z \rangle = 0.35$
with ~ 50000 galaxies

**Future optical surveys (LSST,
BigBOSS)** should measure up to
 $z \sim 1.5$ with up to 10^9 galaxies but
limited by the z determination
(spectroscopy vs photo- z)

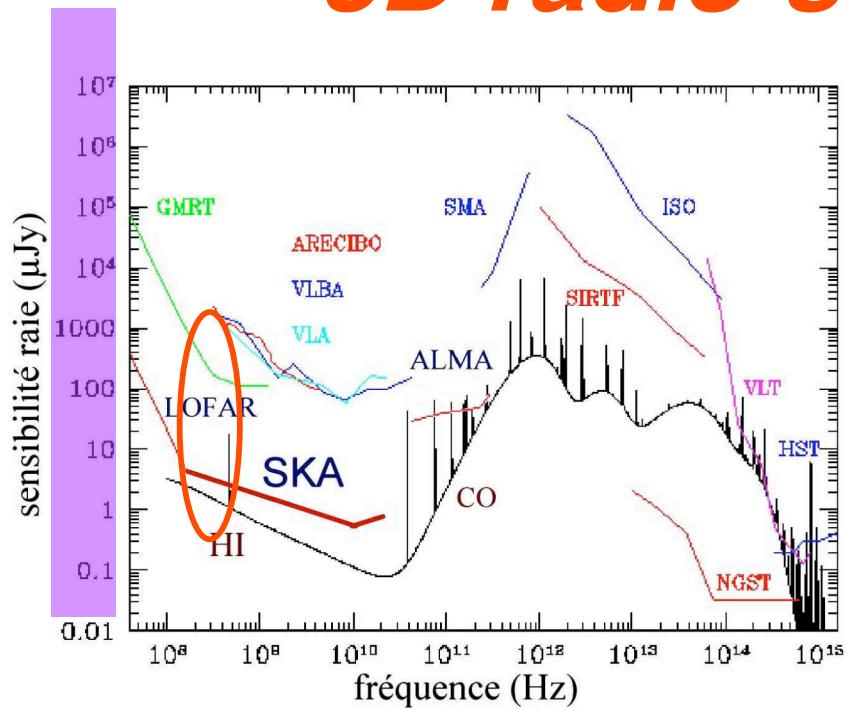
H₂₁ radio-survey

can produce « low-resolution » maps of
HI (galaxies not resolved), but with
excellent redshift determination (line of
sight correlations easy)

-> BAO radial+transverse scales



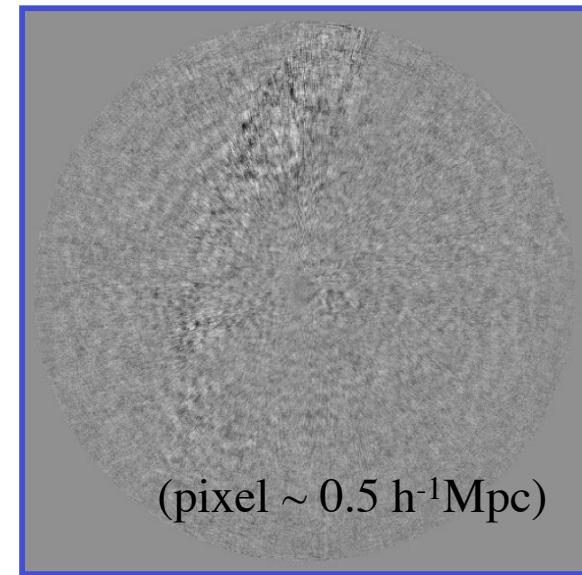
3D radio-survey for BAO



- No need for one-by-one galaxy detection
 - ⇒ Pixel map of H_{21} flux
 - ⇒ Brightness temperature variation
 - ⇒ pixels should be smaller than 20-30Mpc to measure 150 Mpc structures $\sigma_8 \sim 20'$
 - ⇒ *T. Chang et al. PRL 100 091303 (2008)*
 - ⇒ *R. Ansari et al. arXiv:0807.3614 (2008)*

Principle

- Simultaneous determination of position and redshift with the 21cm atomic hydrogen emission line (1.4 GHz @ z=0)
- H_{21} line dominates below 1.4 GHz



HIPASS survey

BAO with FAN

**Wide field
Wide band
at the Nançay Radio Telescope**



The Nançay Radio-telescope

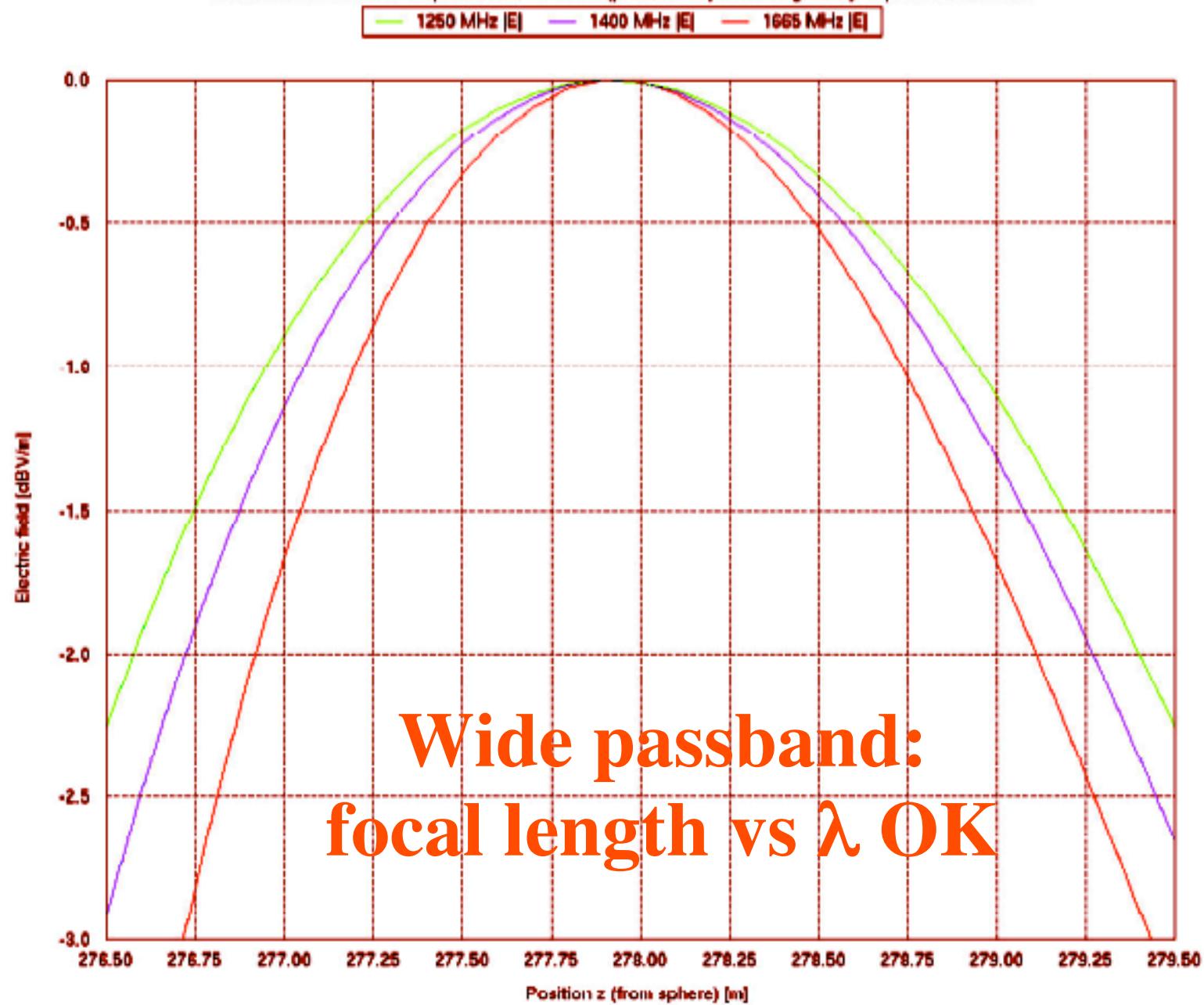
Static spherical mirror 7000 m²



Focal plane $\sim 30\text{m} \times 3\text{m} = 4^\circ \times 0.4^\circ$

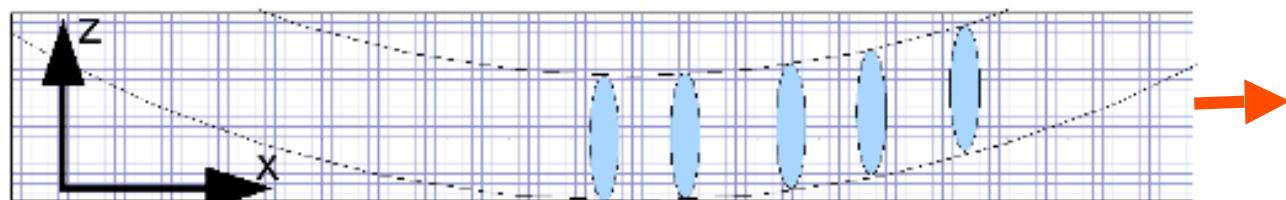
Orientable plane mirror

Scattered electric field - Depth of field - Polar H (plane wave parallel to ground) - Sphere 200m x 35m

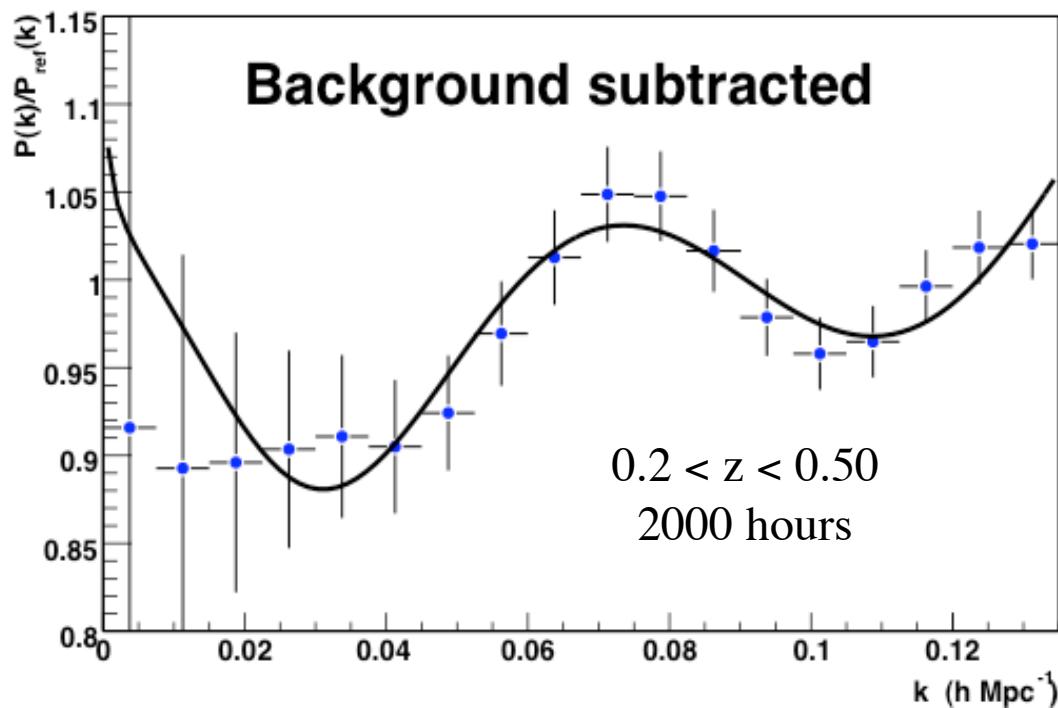


BAO with the NRT

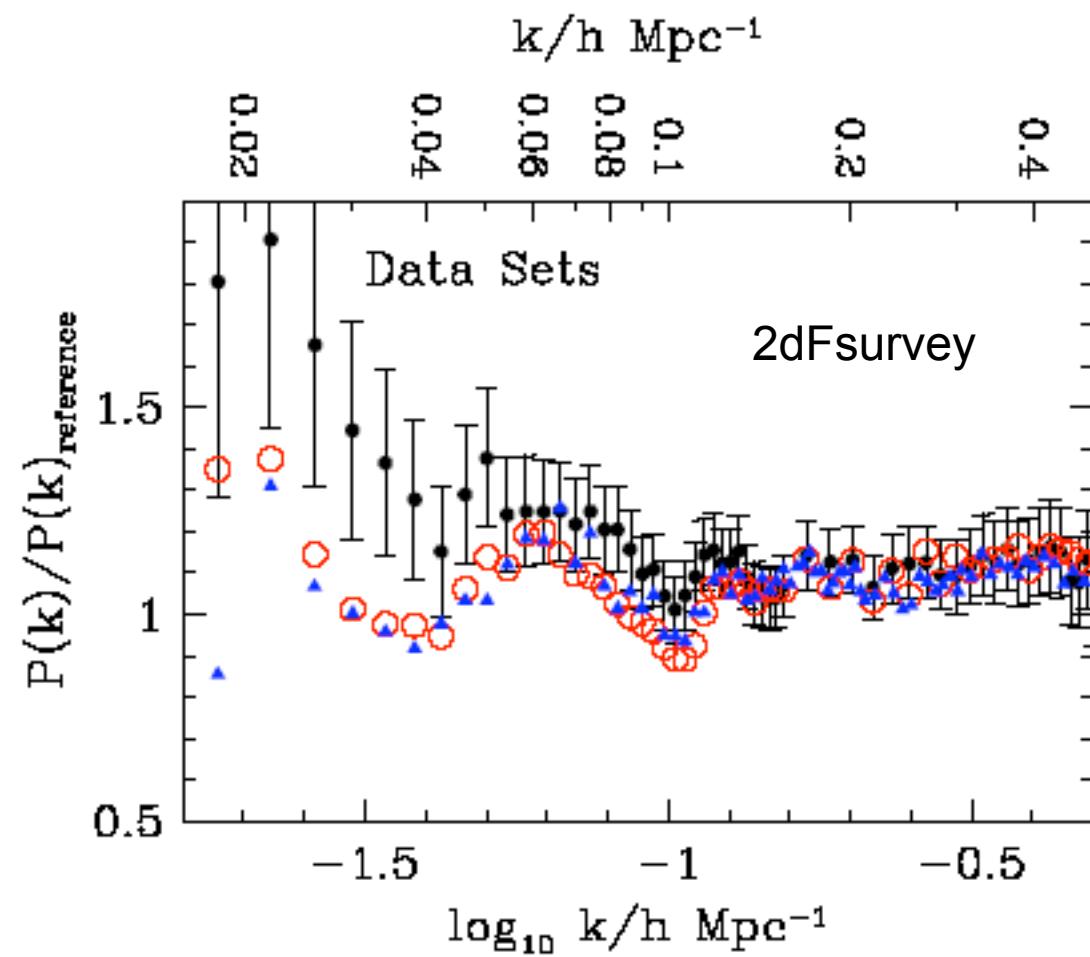
- Install series of antennas at the focal plane to get ~ 100 lobes



Gain a factor of ~ 100 on detection efficiency



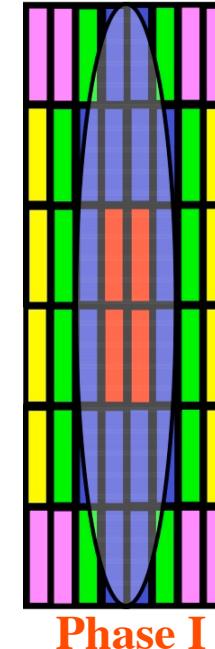
- Simulation for 2 frequency domains :
 - 950-1200 MHz ($0.2 < z < 0.50$)
 - 750-900 MHz ($0.6 < z < 0.9$)
- reach 4σ observations with a survey of 1000-2000 hours
- Precisions: $\sigma(\Omega_m)/\Omega_m \sim 5\%$, $\sigma_w/w \sim 10\%$



Strategy

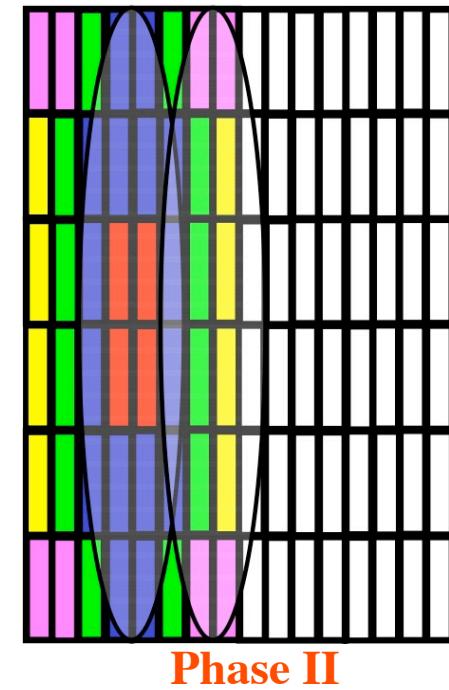
Phase I (under construction)

- Sample the amplitude and phase distributions at the NRT focus
- With 1x3m array of Vivaldi antennas
- 12-32 electronic channels Saclay-LAL (digital electronics with 250 MHz bandwidth)
- Support from PNCG and CS 2008



Phase II (FAN 2010-2012)

- 3m x 7m, ~500 antennas
- 96 digital channels
- real-time correction of the coma aberrations (Beam former)



Phase III

- Focal plane fully equipped (~ 2013-2015)

Proof of the physics concept with phase II

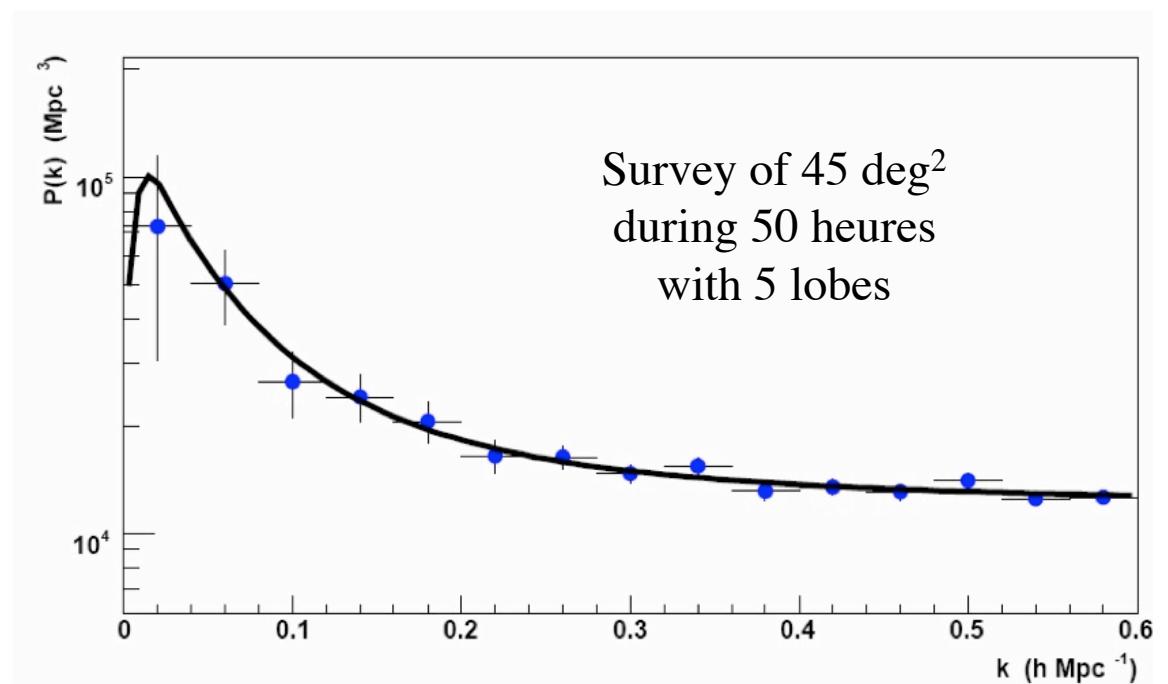
The new idea

- unresolved galaxies \Rightarrow subtract radio-sources (similar to LOFAR...)
- Technical and scientific feasibility to be established !!!

Measure HI power-spectrum

- Cross-correlation between 3D HI maps and SDSS optical galactic survey
- Power spectrum and bias determination at 10%

$$P_{\text{HI}}(k) = b^2 \cdot P_{\text{LSS}}(k) + P_0$$



Conclusions

FAN : a projet to study dark energy

- First BAO studies with HI
- Competitive with optical SDSS or AAΩ surveys
- Can reach $z \sim 1$ not accessible by current surveys

FAN : upgrade of a french facility

- BAO survey will need 20-30% of time
- Gain is ~ 100 for all surveys
- Systematic searches for pulsars in zones that are not visible with Parkes and Arecibo.
- Observation of extended objects : comets, stellar winds...

